PREFERRED FREQUENCIES IN THE HUMAN ELECTROENCEPHALOGRAM

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THESIS

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HUMAN ELECTROENCEPHALOGRAM

by

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activities. Findings related to the behavior of particular frequencies at various scalp positions are discussed. Primary emphasis is on the motor cortex and the junction of the temporal, parietal and occipital regions. Data is presented indicating that frequency ranges 4-8 Hz and 60-120 Hz show increased correlation between closely spaced electrodes when subjects are presented with tasks. Other possible preferred frequencies related to activities such as limb movement, multiplication and reaction to light are presented. A pilot simulation, the Heads Up Display, was found to be an excellent subject tasking mechanism.

Preferred Frequencies in the
Human Electroencephalogram

by

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Submitted in partial fulfillment of the
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Past efforts in spectral analysis of the electroencephalogram at the Naval Postgraduate School are reviewed. Preferred frequencies are defined as those frequencies which exhibit increased magnitude or duration when a subject is engaged in specific activities. Findings related to the behavior of particular frequencies at various scalp positions are discussed. Primary emphasis is on the motor cortex and the junction of the temporal, parietal and occipital regions. Data is presented indicating that frequency ranges 4-8 Hz and 60-120 Hz show increased correlation between closely spaced electrodes when subjects are presented with tasks. Other possible preferred frequencies related to activities such as limb movement, multiplication and reaction to light are presented. A pilot simulation, the Heads Up Display, was found to be an excellent subject tasking mechanism.

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I. INTRODUCTION

A. THE RESEARCH PROJECT

A continual effort has been underway in the Bio-Engineering Laboratory since 1972 directed towards an analysis of the electroencephalogram (EEG) and the extraction of useful information from the EEG's of individuals not afflicted with any known pathologies. Hopefully, some of this information will include signals indicating, in some recognizable way, the mental state of the subject, particularly his degree of attentiveness and his receptiveness towards learning.

This information would be fed back, in some form, to the subject and would enable him to monitor his mental state and to enhance his attentiveness or to move himself towards a state conducive to learning. The successful achievement of this goal has many practical and realistic applications.

Individuals engaged in physically sedentary, but mentally active tasks such as radar or sonar operators, tend to become less alert as their watch progresses, often without being aware of their reduced effectiveness. A feedback mechanism would enable them to retain a level of alertness throughout the watch.

Everyone has experienced moments of mental clarity and lucidity where all mental processes seem to be functioning ideally and problems previously unsolvable are reduced to solution. Unfortunately, we must also endure periods of mental sluggishness, where decision making is arduous, errors are frequent, and the simplest of problems seems hopelessly difficult.

If these periods of crisp, accurate thought processing could be identified by EEG filtering techniques and fed back to the subject, it is conceivable that he could learn to consciously, or subconsciously, enhance those patterns indicative of the desired mental state. Further, should this prove to be successful, the subject should be able to achieve the desired condition without the external feedback after a period of training, as internal feedback would be possible through recognition of the appropriate mental milieu.

In order to analyze the EEG, a series of computer programs has been developed by the team, progressing from the relatively simple early frequency spectrum programs to the more sophisticated multi-channel programs using signal processing techniques which bring desired signals out of a noisy background.

Several theses have been done in the past discussing the results and conclusions reached by the team efforts at progressive stages in the project development. A great body of data has been collected and reviewed by different individuals for varying purposes.

B. THE AUTHOR'S CONTRIBUTION AND OBJECTIVES

It is the intent of this paper to review critically the development of the project, discuss past results with an eye towards frequencies in the EEG which seem to be related to specific activities, and using the insight gained, to show how this information can be put to practical use. A more specific goal is to identify certain frequencies in the EEG which can be shown to be indicative of particular mental activities and may be termed "preferred" frequencies. These preferred frequencies may exist, to some extent, throughout the entire brain, or may be localized in some specific area of the brain.

The author has reviewed an extensive body of data from early project efforts. The knowledge gained was applied to the design of new programs and the restructuring of old ones to investigate clues given by the early data. The results from these new programs are analyzed and tentative conclusions drawn.

II. BACKGROUND

A. THE ELECTROENCEPHALOGRAM

1. Source

The electroencephalogram which is recorded from the surface of the scalp consists of continuous rhythmic potential variations. The precise method of generating these potentials has not yet been completely determined, but broad areas of understanding are well established and widely accepted.

Nerve cells are generators of electrical activity and they are found in abundance in the brain; estimates go as high as 10^{10} in the cerebral cortex alone [Ref. 1]. These neurons come in a remarkable variety of sizes and shapes and their functions in multi-neuronal circuits are still unclear. Current feeling is that the EEG may be largely attributed to the activity of pyramidal cells located throughout the cortex [Ref. 2].

A multitude of investigators has attempted to show the correlation between the observed EEG and intra-cellular post-synaptic potentials (PSP's) of the pyramidal cells [Ref. 3]. These studies have not been conclusive but strongly indicate that the EEG is due to the gross summation of the fields caused by the electrical activity of individual pyramidal cells. The correlation appears to be statistically

sound and increases when adjacent cells can be made to act synchronously.

These studies have been done, to a major extent, on animals since intra-cellular response in a human is seldom possible unless in conjunction with neurosurgery. Mammalian cerebral organization is highly similar to that of man and the carry over of conclusions to humans is felt to be justifiable. In animals, synchronous neural activity is usually achieved by anti-dromic stimulation of cell groups. This presents an artificial environment which has already been removed somewhat from reality by the necessary requirement for anesthetics.

Keeping these alterations to a normal functioning environment in mind, it is possible to draw tentative conclusions. It appears that the EEG is directly related to pyramidal post-synaptic activity and that when cell groupings act in concert, the EEG bears a striking resemblance to the PSP of a given cell in that functional group /Ref. 4/.

2. Localization

Recent evidence strongly suggests a columnar structure to cerebral organization. Vertically oriented (perpendicular to the cortex) cells are organized in columns, each cell in a given column having a purpose similar to that of its neighbors. When the column receives a mild excitation

from some efferent source only a few of the cells are stimulated. However, when the excitation is intense, the entire column may be activated, each cell stimulating its neighbors to greater electrical activity and simultaneously inhibiting adjacent functional columns /Ref. 5/.

These activities will be seen in the EEG when electrodes are placed close to the responding column. If there are certain rhythms and frequencies characteristic of this particular column, spectral analysis brings them forth. It may be possible to determine when a functional group is activated and when it is not.

In order to locate a source of electrical activity in the brain, a knowledge of the conductive properties of the brain, skull and scalp is essential. Because brain tissue is an excellent conductor, activity in one portion of the brain will be reflected to some extent in electrodes placed anywhere on the scalp. Unfortunately, no thorough studies have been made giving a conductive map of the human head. Models have been created which satisfy some basic aspects of signal behavior, but it is unclear whether some observed waveshapes are due to impedance changes, and uncertain just how much effect the capacitive properties of tissue have in the phase of signals observed at different electrodes.

Ideally, and perhaps in most cases, the electrode receiving the strongest signal is the electrode closest to the source. However, this may not always be the case since discontinuities in conductance in the various types of brain tissue and fluids may cause a signal to be passed more easily to a more remote electrode.

3. Frequency Generation

If the EEG is a summation of the PSP's of a group of neurons beneath a recording electrode, it should be possible to devise a model which, using known physiological parameters, can reproduce signals seen in the EEG.

Computer programs were designed at the Bio-Engineering Laboratory which achieved this goal. The post-synaptic potentials of a neuron are caused by the excitation of synapses which allow the passage of current to alter membrane potentials. These potentials, excitatory and inhibitory, are characterized by a rapid rise or fall followed by an exponential decay to the resting potential. The extra-cellular fluids in the vicinity of the cell must complete the current loop and potential drops across the resistance of the fluid follow the same rise and decay. The summation of potential drops due to the excitation of many cells is seen at the scalp as the EEG.

Assuming that adjacent cells in a functional column act synchronously, a model which creates a PSP for one cell should suffice for the entire column. The model entails the formation of an excitatory response to a single synaptic input such as is seen in Figure 2-1A. An inhibitory response is also formed which is much the same only of reversed potential and having slightly different time constants.

Excitatory and inhibitory inputs are then given to the modeled cell which responds by summing the exponential responses to each input, providing an appropriate time (refractory period) has passed since the last output. This summation is very similar to the PSP of a neuron. Inputs may be random or specially designed in frequency to recreate a known physical situation. Some typical inputs are shown in Figure 2-1B and the resultant PSP in Figure 2-1C. The sinusoidal appearance of the PSP is frequently seen in the EEG. The discrete Fourier transform of this modeled PSP is given in Figure 2-2.

Neurons in the Central Nervous System may fire as often as 1000 times per second. With this rate of excitation, it is easily seen how higher frequencies can arise in the EEG and how, through spectral analysis, information may be extracted from the EEG on the rate of excitation or inhibition of particular groups of cells.

A. Response to single input at t=0

B. Inputs; excitatory is upper trace, inhibitory is lower

C. Final PSP

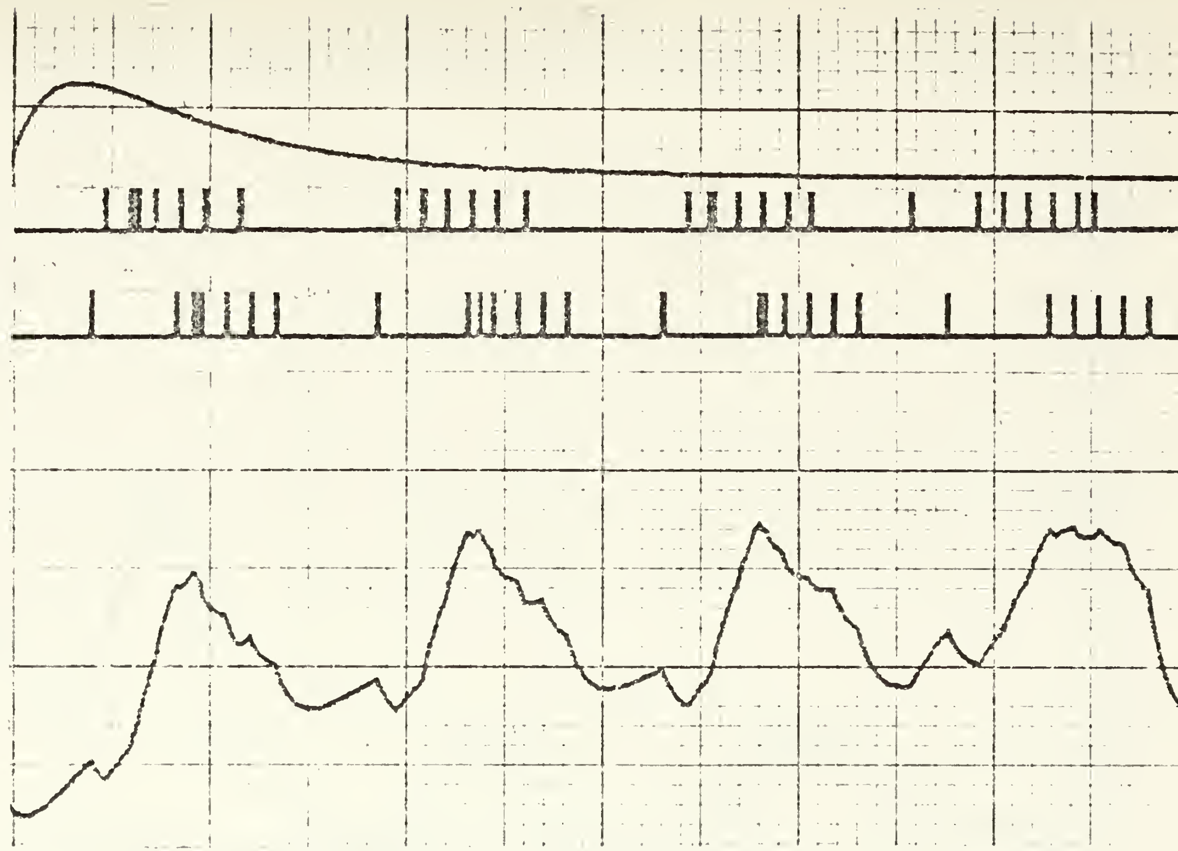


Figure 2-1

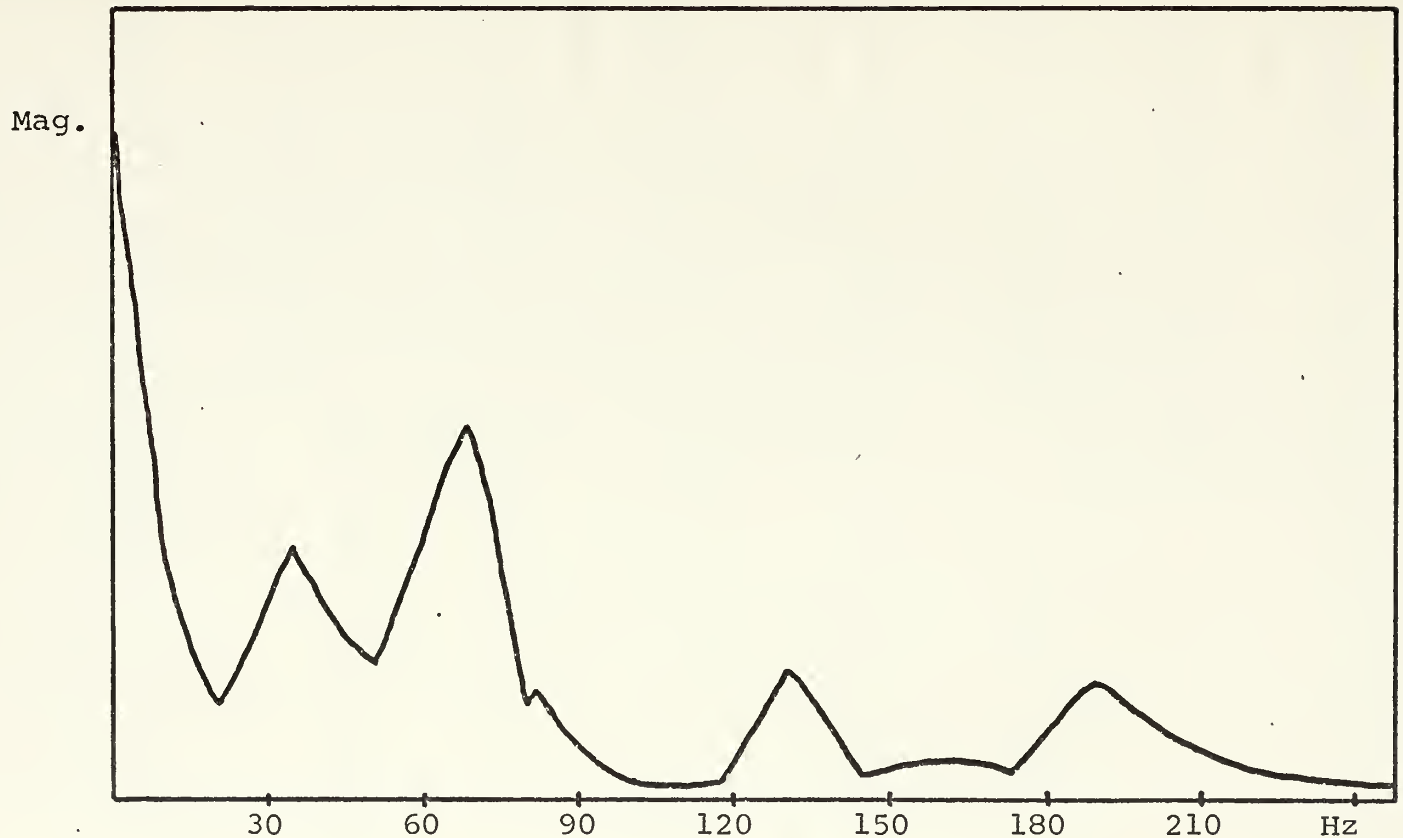


Figure 2-2, Discrete Fourier transform
of signal in Figure 2-1,C

A given cellular circuit may have a characteristic frequency which it exhibits when stimulated. If this frequency (or frequencies) can be identified through spectral analysis it may then be possible to determine by external means whether particular areas of the brain are functioning abnormally.

B. EQUIPMENT AND ENVIRONMENT

There are three basic electrode recording modes, each having its own advantages. A recording mode is chosen based upon the desired results. A monopolar recording is referenced to an electrode placed over a presumed inactive site. This electrode provides one input to a differential amplifier while the signal from an electrode placed over the area to be investigated provides the other input. The reference position is assumed to be "indifferent" to brain electrical activity such as the mastoid, ear or bridge of the nose. The amplifier is grounded to the subject at a point below the reference, such as over the collar bone, to remove myograms and electrocardiogram signals.

The bipolar recording mode has certain advantages over the monopolar. This mode employs two electrodes usually closely placed over the area to be investigated. The leads from the electrodes are fed into the two inputs of a differential amplifier and the difference is amplified. Activity

common to both electrodes is canceled whereas the signal from the active site is amplified if the electrodes have been positioned properly. However, if the signal from the generator is in phase at both electrodes, it will tend to be canceled. Both the bipolar and monopolar modes may be used with as many electrodes as there are available amplifiers.

The average electrode method is often used with multiple electrodes. In this method, one of the inputs to each amplifier is connected in common and passed to the other input through a relatively large resistance (locally 80K Ohms). This arrangement essentially cancels the summed average signal and records the differences beneath each electrode. A superior averaging method is used more frequently at the Bio-Engineering Laboratory which averages the signal with computer software, as is done in TWODET. This is elaborated on in Part IV-D of this paper.

Each of the methods just discussed has been used locally. The choice is dependent upon the suspected nature of the signal desired to be observed. More information on electrode modes may be found in Refs. 6 and 7.

The laboratory environment has been discussed at length in the above references. Figure 2-3, taken from Ref. 6, gives a block diagram of the experimental set-up.

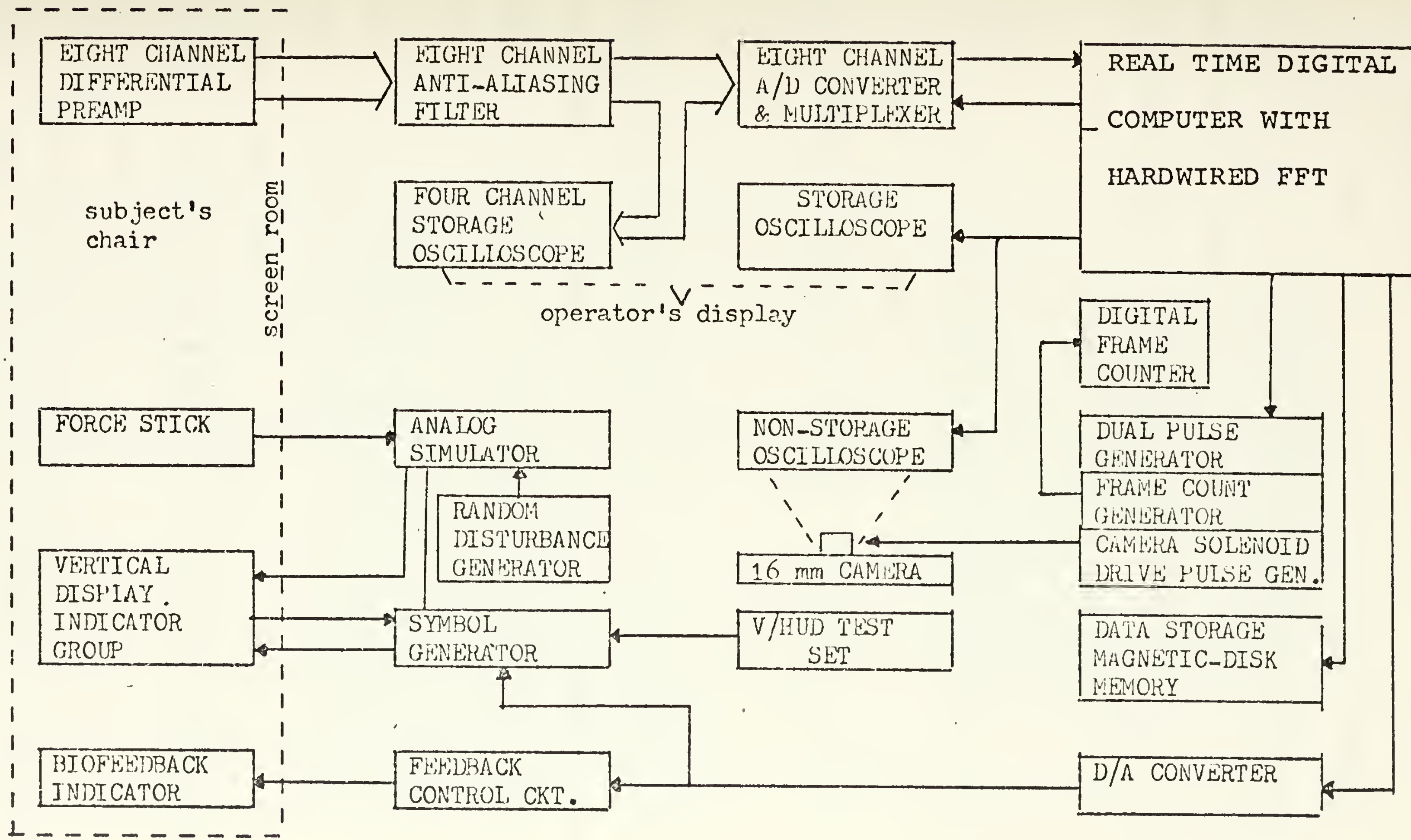


Figure 2-3. Block Diagram of experimental set-up.

Signals from the scalp are sensed by Beckman 2mm silver electrodes through a conductive material known as Sucablok, a Swedish trade name. The electrodes and Sucablok are held in position by a threaded plastic device that is placed in the desired position on a specially designed helmet. Figure 2-4 shows both an individual electrode and the helmet.

From the electrodes, signals are fed into an eight channel differential amplifier with a common mode reflection ratio greater than 90dB. These analog signals are converted to digital data and made available to the PDP-11/40 for processing. The laboratory has facilities for recording results on tape, disk, paper plots, and film.

The subject and pre-amplifiers are placed in a screen room to provide isolation from ambient RF noise and signal radiation. The removal of any electromagnetic signal not having its source in the brain is essential. The screen room and common mode rejection of the differential amplifiers are extremely effective in reducing external noise but it is also necessary that minimum noise is generated by the amplifiers themselves. The operational amplifiers used here were chosen to have less than 2.5 microvolts of noise for frequencies up to 10kHz.

This requirement for extremely low noise is illuminated by the audio evoked response experiments conducted locally.

The helmet with electrodes

Electrode; assembled and disassembled

Figure 2-4

It was determined through averaging techniques that the audio evoked response has consistent, meaningful components with peak to peak values less than 2 microvolts.

Before the analog data is digitally converted, it is passed through anti-aliasing filters. This is absolutely essential if any meaningful results are to be obtained when a signal is to be discrete Fourier transformed. If the frequency spectrum of the signal to be sampled is not compatible with the Nyquist criterion sampling rate, the frequency spectrum folding due to sampling will cause high frequencies to masquerade as lower ones, giving completely erroneous data.

Four pole Butterworth filters are used for this purpose due to their excellent cut-off and phase characteristics. They are designed as removable cards so that the spectrum may be adjusted according to the frequencies of interest.

III. THE DISCRETE FOURIER TRANSFORM (DFT)

Every program used in this investigation has made use of the time to frequency domain transformation of the DFT. This is done digitally by a special hardware processor which utilizes the Fast Fourier Transform decimation-in-time algorithm.

Perhaps the most important fact to be kept in mind when analyzing data obtained from a DFT process is that the frequency resolving ability of the transform is limited by the time window (T). One must choose a particular time frame of data he wishes to transform: the frequency discrimination of the transform will be the reciprocal of the time window.

If the goal of the investigator is to observe the DFT, (or make use of the DFT in a more complex program), on a continuous real time basis, the time window is necessarily small giving rise to poor frequency discrimination. This effect was overcome by the project team by employing a sliding time window concept which used a time window of 4 seconds updated each second by adding a fresh second of data and dropping the oldest second. Thus the frequency discrimination, or resolving ability is one quarter Hz yet the display is updated every second.

The time window effectively multiplies the time domain signal by a rectangular pulse of duration equal to the window in seconds. In the frequency domain, this is equivalent to convolving the signal spectrum by the transform of the time window which is a (sin x)/x function. The DFT display will show frequencies at the fundamental (reciprocal of the time window) and all harmonics up to N/2, where N is the number of sampled points in the data to be transformed.

If the signal to be transformed is a harmonic of 1/T and has an even number of periods contained in the window, the DFT display will be a single bar (or point) at the signal frequency. Signals not ideally captured by the window or not harmonics of the fundamental will be displayed as a series of bars whose envelope describes a (sin x)/x curve. The import of this is that frequencies not at the precise frequencies in the actual signal will appear in the DFT because the transform process treats that portion of the signal captured as one period of a periodic function to be transformed. In addition, phase cancellation can cause the complete disappearance of some of the spectral components of a complex signal.

This problem can be alleviated by the Hanning function which multiplies the window by a cosine bell shaped curve which eliminates the discontinuities between periods.

Unfortunately, this function widens the main lobe of the (sin x)/x curve and makes frequencies in the display appear less discrete. It was determined early in the program that the disadvantages of Hanning outweighed the advantages for the type of investigation done here and has seldom been used.

IV. PROGRAM DEVELOPMENT AND PAST RESULTS

A. FSEG

One of the first programs developed, known as FSEG, was designed to display the DFT of signals coming from four different electrodes; frontal, temporal, parietal and occipital in most cases. The sampling rate was 256 Hz making the DFT valid to 128 Hz and the anti-aliasing filters were adjusted accordingly.

Initial runs immediately verified the existence of the well known frequencies seen by early investigators. These had been named delta, theta, alpha and beta for frequencies of approximately 0-4, 4-8, 8-13, and 13-50 Hz respectively. These frequencies have received a great deal of attention by serious investigators and mystics alike. It seems clear now that different mental states produce different combinations of these frequency bands. Alpha feedback monitors seem to aid in bringing increased relaxation and release of tension to a subject who attempts to increase his production of alpha.

These frequencies were far and away those having the largest magnitude of FSEG. A typical display is shown in Figure 4-1. It was observed that the relative magnitude of these frequencies might change from electrode to electrode, but were present to some extent in all.

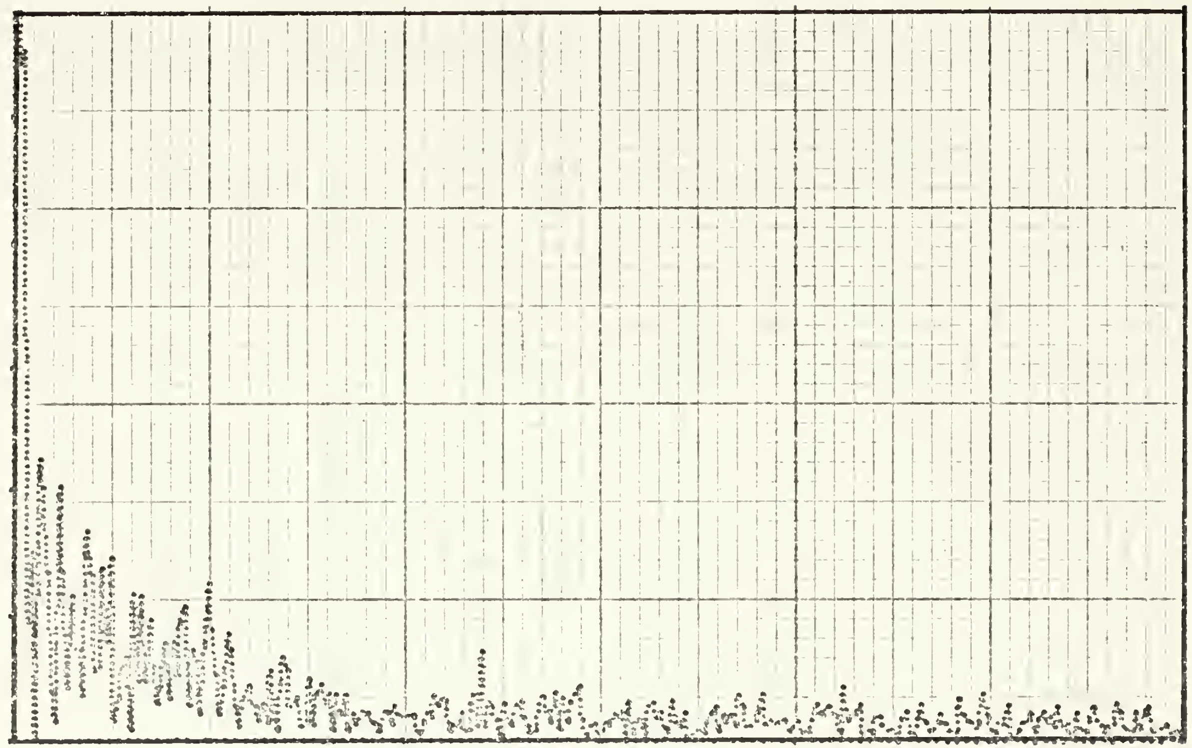


Figure 4-1. Typical FSEG type display

Attempts were made to determine how the frequency spectrum changed with differing mental states or activities. Typically, the DFT was observed for eyes closed and eyes open in both relaxed and problem solving conditions. Opening the eyes usually causes a drastic reduction in the production of low frequency waves, particularly alpha, in most subjects. This is a well known phenomenon and has been discussed at length by many investigators and several hypotheses have been developed to account for it.

Perhaps one of the most interesting speculations is that alpha is a strobing signal, a clocking mechanism keeping activated areas of the brain which are not being stimulated through some physiological necessity. Alpha, or alpha-like signals have been observed in other mammals as well as in man. It may well be that the function of alpha is to maintain a minimum degree of alertness or readiness to react to unexpected situations. This view is supported by evidence which indicates that alpha is initiated in the reticular activating system.

The constant changing of the spectral components as observed in FSEG experiments led to the desire to view, in real time, the activity in particular frequency ranges. This led to the development of TEG4.

B. TEG4

In many subjects studied initially, there was a large frequency component in the 18-25 Hz range. It appeared from FSEG data that this was independent of the alpha. A program called TEG4 was developed which could filter the signals received from four electrodes by selectively zeroing portions of the DFT and then performing an Inverse Fourier Transform (IFT). Also, the program had the capability to take the signal from one channel only and display four different filtered bands.

This 18-25 Hz frequency band did appear to be related to alpha range frequencies in that it generally seemed to wax and wane with alpha, particularly in electrodes towards the rear of the head. TEG4 gave evidence that the 20 Hz band was not a harmonic of alpha in that the filtered spindles appeared at different times and durations than did the alpha [Ref. 6].

Feedback experiments on this frequency range were not conclusive but several subjects demonstrated the ability to increase or decrease the signal in this band at will. The successful runs occurred mainly when individuals attempted to enhance the 20 Hz signal from the frontal electrode.

In most subjects the frontal region appeared to generate (or receive) its alpha independently from that in the other

electrodes. TEG4 results frequently show the alpha range signal in the parietal and temporal regions to be combinations of the signals in the frontal and occipital areas. Figure 4-2 shows how a typical TEG4 result might appear.

In studying FSEG results, it was observed that the display usually contained several discrete frequencies of relatively large amplitudes when compared to their neighbors. These seldom seemed to be associated with specific activities, would usually change with each new frame, and differed from electrode to electrode. These frequencies were a matter of concern initially since discrete frequencies of this type should only be possible if the signal was a relatively pure since wave lasting the duration of the window. Reference 8 develops the current position that these discrete frequencies are the result of several spindles of a particular frequency range occurring randomly within the time window.

It had been observed that the EEG had momentary bursts of activity at different frequencies. The bandpass filtering of TEG4 enabled these frequencies to be separated from the full spectra signal and observed. The spindle like bursts of activity were given the coined term tegules and were felt to be unit signatures of cortical activity.

The tegule was investigated vigorously and tentative conclusions were drawn for frequencies up to 50 Hz.

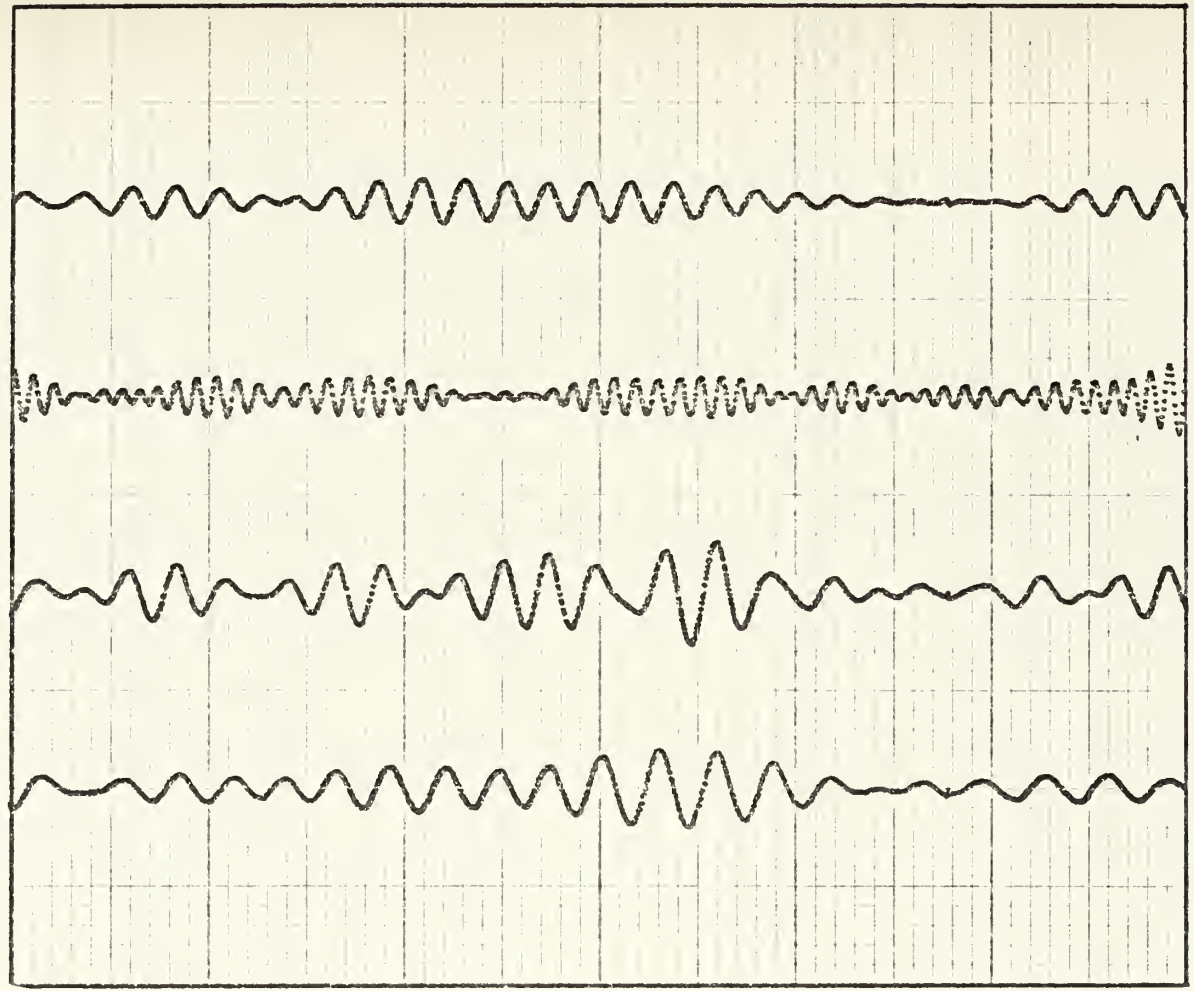


Figure 4-2. A display of the type seen in TEG4. Each trace could be filtered at a different frequency

Frequencies below 14 Hz were not felt to exhibit tegule like behavior as they showed no consistency of duration, but tegules existed between 14 and 50 Hz. At this stage of the investigation, no consistent data was obtained as to the variation in amplitude and duration with subject activity, and the mental states of the subject appeared to have little affect on either of these parameters. Using the frontal, temporal, parietal and occipital electrode configuration it was seen that as the frequency band observed was raised, the four signals became increasingly dissimilar [Ref. 6]. Later data (see Part 5B) defined situations where increased correlation occurred.

C. XSEG AND XCORR

In order to obtain more concrete information on this finding, cross spectra and cross correlation programs were designed, XSEG and XCORR respectively. The thinking at this time was that if the brain acts as a parallel processor, then during states of concentrated, directed activity or problem solving, separate areas of the brain should show increased correlation.

Using these two programs it was seen that when a subject is in a relaxed state, there is little correlation between the signals above the alpha region in widely spaced electrodes, whereas closer ones showed increased similarity. However,

when in a problem solving status, separated electrodes show increased correlation times.

D. SYNCHRONOUS DETECTION METHODS

1. TWODET

Following the leads from XSEG and XCORR, synchronous detection programs were developed. TWODET and its variant, DSKDET, have been the most fruitful tools in the identification of preferred frequencies. The essence of TWODET is that the signal from eight electrodes referenced against a ninth (usually the vertex) are averaged and this average is then subtracted from the signal from two closely spaced electrodes (7/8 inch) located in an area of interest. Note that the latter two signals are included in the average. The two resultant signals are digitally bandpass filtered and cross multiplied. This synchronous detection method, which is discussed in more detail in Ref. 7 indicates the degree of correlation between two signals.

The two original signals, the cross multiplied signal, and the average from the eight electrodes are recorded on a disk for later analysis and review. A program was designed to take the cross multiplied data from the disk, zero out all negative components, integrate the remaining positive correlation in one second increments and display the integrated values in a bar graph form for any

time frame desired. This final graph when covering a period of time in which a subject was engaged in differing activities often shows marked correlation changes from one type of activity to another.

2. DSKDET

To allow greater flexibility in frequency investigation and to preclude the necessity for keeping subjects engaged for prolonged periods of time, a variation of TWODET was devised. EEG signals from two closely spaced electrodes are low pass filtered to 1600 Hz and recorded directly on a disk. The two signals are then bandpass filtered at the desired frequency, cross multiplied as before, and one of the original signals is multiplied times itself. Both results are then integrated in half second intervals with negative values in the cross correlation block retained. The integrated values are then displayed as in TWODET.

A major impetus for the creation of DSKDET was to determine if the use of the word correlation was proper. It was felt that the TWODET program design was such that increase in signal strength would result in an increase in apparent correlation. For example, if one assumes that the signals from the two electrodes are always identical, a true plot of their correlation would remain the same despite changes in signal amplitude or degree of occurrence. If

they are identical, they are always perfectly correlated. Since the value used as an indicator of correlation during a particular time frame is obtained by cross multiplication of the two signals and then integrating, if the signals maintain the same actual correlation but increase in amplitude or appear more often in a given time frame, the resultant correlation value may increase dramatically.

Thus, it is valuable to the investigator to have available a display of the degree of signal content in a given session to compare with the correlation display. It can then be determined with greater assurance whether two signals have, in fact, become more correlated.

If significant changes occur in the correlation or signal content of a particular range of frequencies, other ranges may be investigated for that same period of time. This is of value for many reasons, but of particular importance to assure the investigator that these changes are not due to myograms which invariably appear as broad spectrum signals beginning at around 25 Hz and retaining strength out to frequencies in excess of 500 Hz.

This program has a disadvantage in that it is more sensitive to frequencies occurring at the reference position than is TWODET. Thus, unless results are cross checked against TWODET results, the investigator cannot be certain

that the correlation or signal content variations observed are not due to activity at the reference (usually vertex) rather than the area under the two signal electrodes. No inconsistencies have been revealed, to date, in the cross checking of similar runs.

E. HISCAN

A method superior to the DFT process was needed to identify preferred frequencies for further investigation by TWODET and related programs. As previously stated, higher frequencies in the EEG have decreasing amplitudes and in fact may be of comparable amplitude to the skirts about the DFT component of a large lower frequency. A program sensitive to the time a signal was present rather than to its amplitude was called for and HISCAN was developed.

It was evident from TEG4 data that as the observed frequency band was progressively increased, the signals from the electrodes became more dissimilar. The question to be answered was what significance did these higher frequencies have and how may these low amplitude signals be studied.

The desired end in HISCAN is to determine the relative time in a given signal duration a particular frequency occurs. Thus, even though a frequency component at 200 Hz has only one-tenth the amplitude as a 20 Hz signal, if it

is present more often than the 20 Hz signal it will be displayed with more weight.

This can be accomplished by taking the DFT of a signal from an electrode, then bandpass filter the signal with a sliding frequency window of optional size. The filtered frequency domain data is then subjected to an IFT and the number of positive zero crossings is counted. The counts are inverted to frequency data and must be appropriately weighted as higher frequencies will naturally tend to have more zero crossings than low frequencies. Once weighted, a relative value is obtained representing the time a given frequency was present. The data block containing the counts for each frequency are available for visual display or plotting.

In order to smooth out the display, a subroutine allows the operator to take a "running average" of a chosen number of words in the histogram block. Each word in the block is averaged with a given number of its neighbors and this average replaces the count in the block. Additionally, an option is available to zero out those frequencies in the DFT whose magnitude is less than a chosen value. This subroutine can assist in removing frequencies due to amplifier and other noise sources. The operator must be alert in using this clipping subrouting since if the level to be zeroed is

chosen too high, those frequencies contributing to the signal envelope may be removed and the existing frequency will appear to be present more often that it truly is.

In a sense, the great strength of HISCAN is also its greatest weakness. When a burst of a given frequency appears in an electrode signal, its spectrum is spread in the DFT. HISCAN will treat the sidelobes as frequencies of equal strength if they are not zeroed by the clipping routine. As the duration of the signal to be processed is increased, there is a leveling tendency which obscures the actual frequency of the bursts. This is to be expected with a non-stationary phenomenon.

HISCAN, then, calls for a judicious choice of program parameters to bring out the desired results. It has the ability to sense frequencies of smaller amplitude than other methods are capable of detecting, and it can then display these frequencies with a magnitude indicative of their relative duration.

V. RESULTS

A. HISCAN RECORDS

Studies with this program to date have been, for the most part, limited to the motor cortex and the juncture of the temporal, occipital and parietal regions (TOP). Both areas have been studied over a wide range of activities varying from writing words backwards to "flying" the Heads Up Display (HUD).

Figure 5-1 shows a typical HISCAN graph from 4 to 80 Hz. This is the result of processing ten seconds of signal from a TOP electrode during an eyes closed, relaxed session. Note there is a great deal of alpha range activity and large signal content in the area of 20 Hz. Every subject observed had major frequency ranges which were similar to those of the figure. The alpha range existed in each subject, although one may have had it centered at 9.5 Hz while another subject may have had it centered at 11 Hz. Likewise the "20 Hz" signal varied from subject to subject being centered anywhere from 18 to 26 Hz. For a particular individual, however, these frequencies seldom varied more than plus or minus 2 Hz when relaxed. When a subject's eyes were open, the ranges discussed reduced in magnitude and duration, but remained the predominant frequencies for that state.

When subjects were given problems such as simple multiplication or writing words backwards, two noticeable events occurred in every person tested; the alpha and "20 Hz" decreased and frequencies in the 5 to 8 Hz range increased, often dramatically. Figure 5-2 demonstrates this increase for the same subject as in Figure 5-1. This shows the HISCAN results of giving mathematical problems to a subject and recording the TOP signal. This increase in the 5 to 8 Hz range is observed in the motor cortex also, although usually to a lesser degree.

HISCAN was slightly modified to enable the investigator to observe results from brief periods of time on a cathode ray tube prior to averaging over a longer epoch. As previously mentioned, the longer the period of signal time processed, the more frequency leveling occurs. This viewing of intermediate results showed the sequential development of the final HISCAN results.

Figure 5-3 shows one of these intermediate results, again from 4 to 80 Hz. Note the appearance of large discrete frequencies as compared to previous figures. When subsequent frames are examined, these same frequencies may again appear or they may shift slightly. Nothing definitive may be said at this time as to the persistancy of these signals or their relation to specific activities. Future work will entail

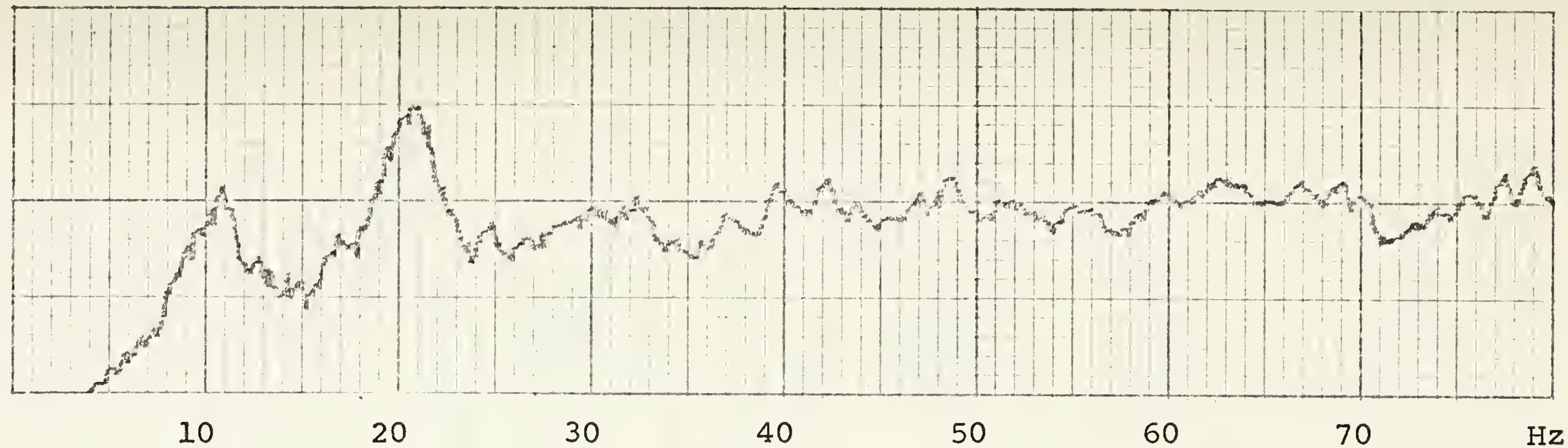


Figure 5-1. HISCAN result from relaxed individual

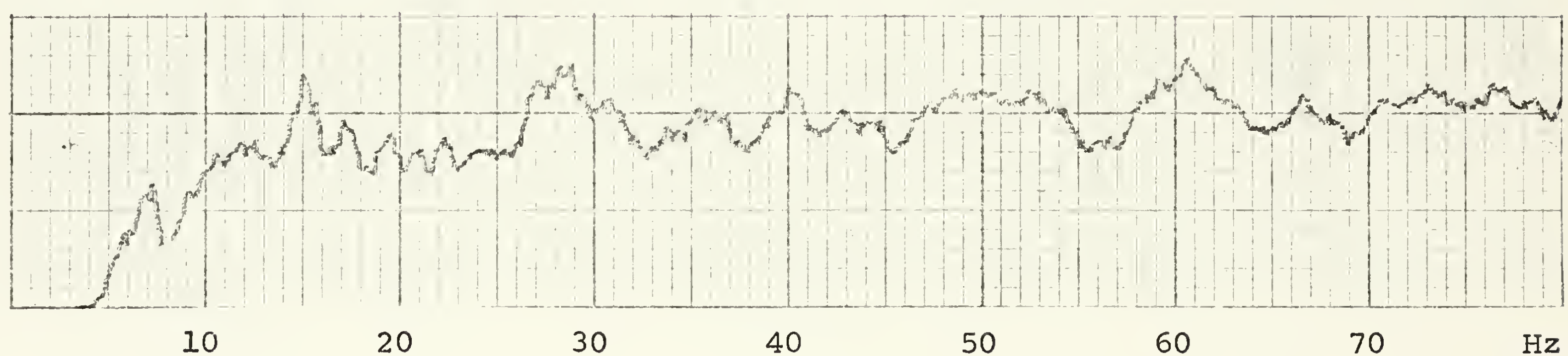


Figure 5-2. HISCAN results when subject is presented with a task. In addition to the increase at 7 Hz, note that several higher frequencies increase.

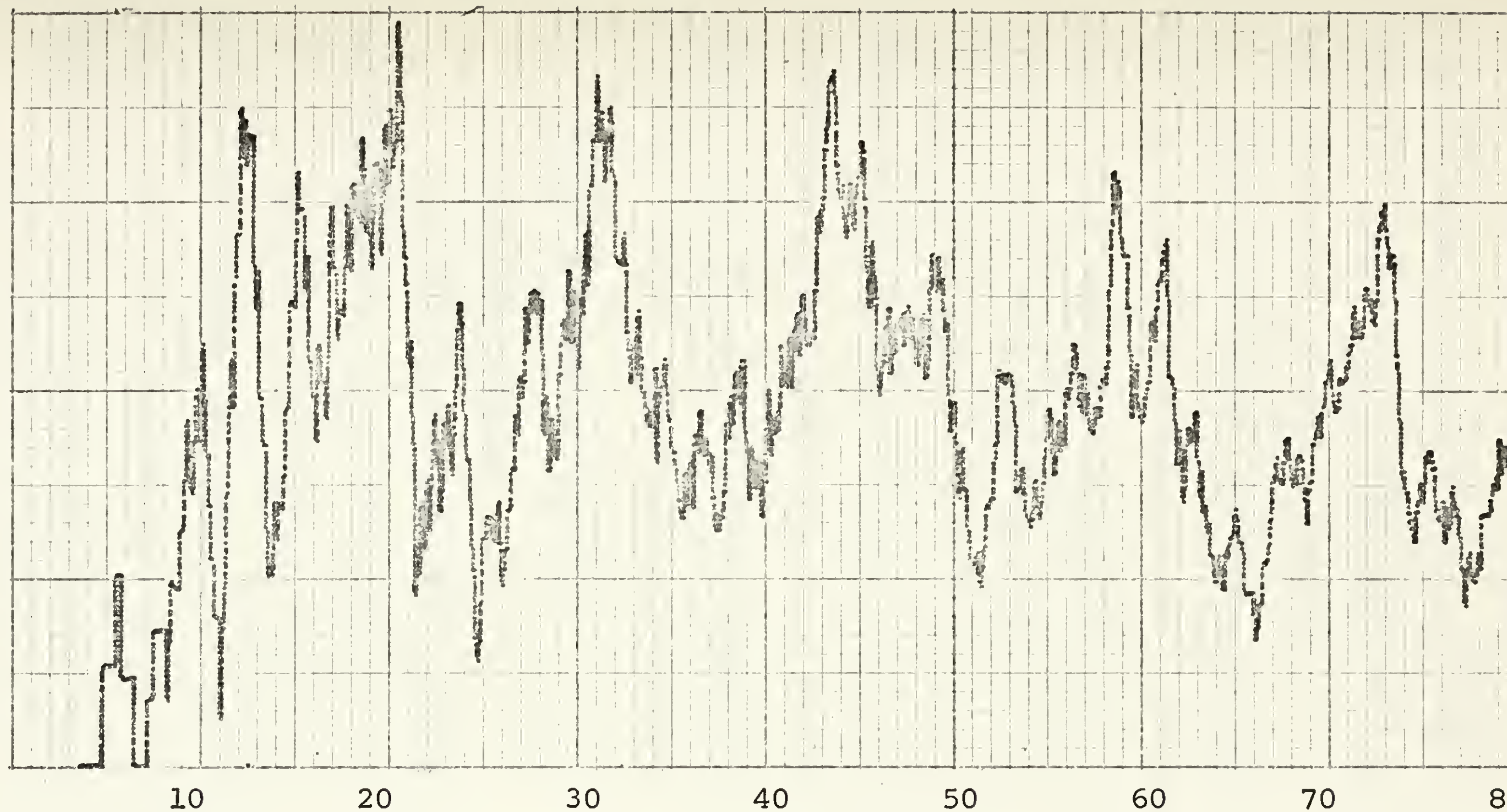


Figure 5-3. HISCAN result from a shorter period of time than Figures 5-1 and 5-2. Note that several discrete frequencies appear.

recording, simultaneously with the EEG data, analog records indicating experimental conditions such as the exact moment a problem was assigned or when a change occurred in the HUD display. This addition will make more specific preferred frequency identification possible.

As the data HISCAN processes is put on the disk by the same method used by DSKDET, there is a tendency to pick up signals from the reference position and possibly from areas between the area being studied and the reference electrode. It has been suggested that future work with HISCAN and DSKDET use bipolar or averaging mode recording rather than the monopolar. By restricting the bandwidth of the recorded signal, the software averaging technique used in TWODET may be used to remove signals from the reference.

B. SYNCHRONOUS DETECTION DATA

1. Initial Results

Initial runs using these methods searched the spectrum between 5 and 100 Hz usually in 20 Hz intervals or bandpass segments. The normal format was 25 seconds of eyes closed relaxed followed by 65 seconds of problems, usually simple multiplication with eyes closed. The two adjacent electrodes were normally placed at the TOP.

When frequencies between 5 and 35 Hz were examined for correlation change, no significant variations were

noticed. This is felt to be due to the fact that this range encompasses several discrete preferred frequencies which act independently and one may increase while another is decreasing resulting in an average which shows no change. When the range was reduced to 5 to 25 Hz, there was often a considerable decrease in correlation during problem sessions.

The range between 65 and 85 Hz usually showed significant increase during problem periods, the average increase in all recorded runs being in the neighborhood of 60%. Some of the subjects tested showed as high as 250% while others might evidence correlation increases as low as 10%. At no time, however, did there fail to be an increase. Frequency ranges 80-100 Hz and 185-205 Hz exhibited similar correlation increases, although usually to a lesser extent. Again, there were striking exceptions; one run showed an increase of 230% in the 80 to 100 Hz range.

2. Myograms

Myograms can be a significant problem if the investigator is not alert. Usually, during a run, myograms due to swallowing, blinking, jaw movement, etc., are very obvious when watching the signals on the four trace analog oscilloscope. These large myograms when observed by the operator will normally cause the run to be discarded. At the least, note will be made in the written record that myograms

occurred at a particular time and that segment of the run is disregarded. A more serious problem are the more subtle forms of myogram caused by slight tension of the forehead or minor movement of the teeth.

On any given TWODET run, the researcher cannot be absolutely sure that the correlation increase was not due to tension myograms caused by minor anxieties during problem sessions. Once a run is completed, he has only the data from the specific frequency range recorded. It has been observed on runs designed to test different types of myograms that they are generally an extremely broad band phenomena. To preclude the possibility of myograms, then, it is desirable to be able to investigate the entire frequency spectrum for that data run. This is one of the reasons for the development of DSKDET. It is felt that results using this program rule out the possibility that myograms are contributors to the observed correlation increases.

The initial results discussed above stimulated a more comprehensive search for other areas which exhibited correlation changes. New frequency ranges were tested and more challenging tasks were devised. The areas studied included frontal, pre-motor, motor and TOP with emphasis in the motor cortex. Activities studied were varied; relaxing, drawing, mathematical and word problems, "flying"

the HUD, movement of various parts of the body, and exposure to different degrees of light.

3. Heads Up Display (HUD)

Much of the recent work by the research group has been based on data collection from subjects engaged in HUD activities. The HUD as used here consists of a cathode ray display which simulates a pilot's view from the cockpit of an airplane. A control stick was attached to the chair normally used for EEG runs which can change the pitch or roll attitude of the airplane on the display in front of the subject. This control is located at the subject's right hand. Experimenters can control, from outside the screen room, these same attitudes, and a system was devised whereby random changes in attitude can be introduced at predetermined rates, thereby simulating varying types of weather, i.e., winds, air pockets, updrafts, etc. This adaptation of the HUD for project use was done by Lt. Dennis Marvel and the system is described in detail in Ref. 9.

The normal TWODET run with the HUD consisted of varying conditions from relaxed to "very rough weather". Typical of these runs is Figure 5-4 showing the degree of correlation between two electrodes in the left motor cortex, filtered to 70-100 Hz, for different types of activity. This run contains six 100 second periods of different tasks.

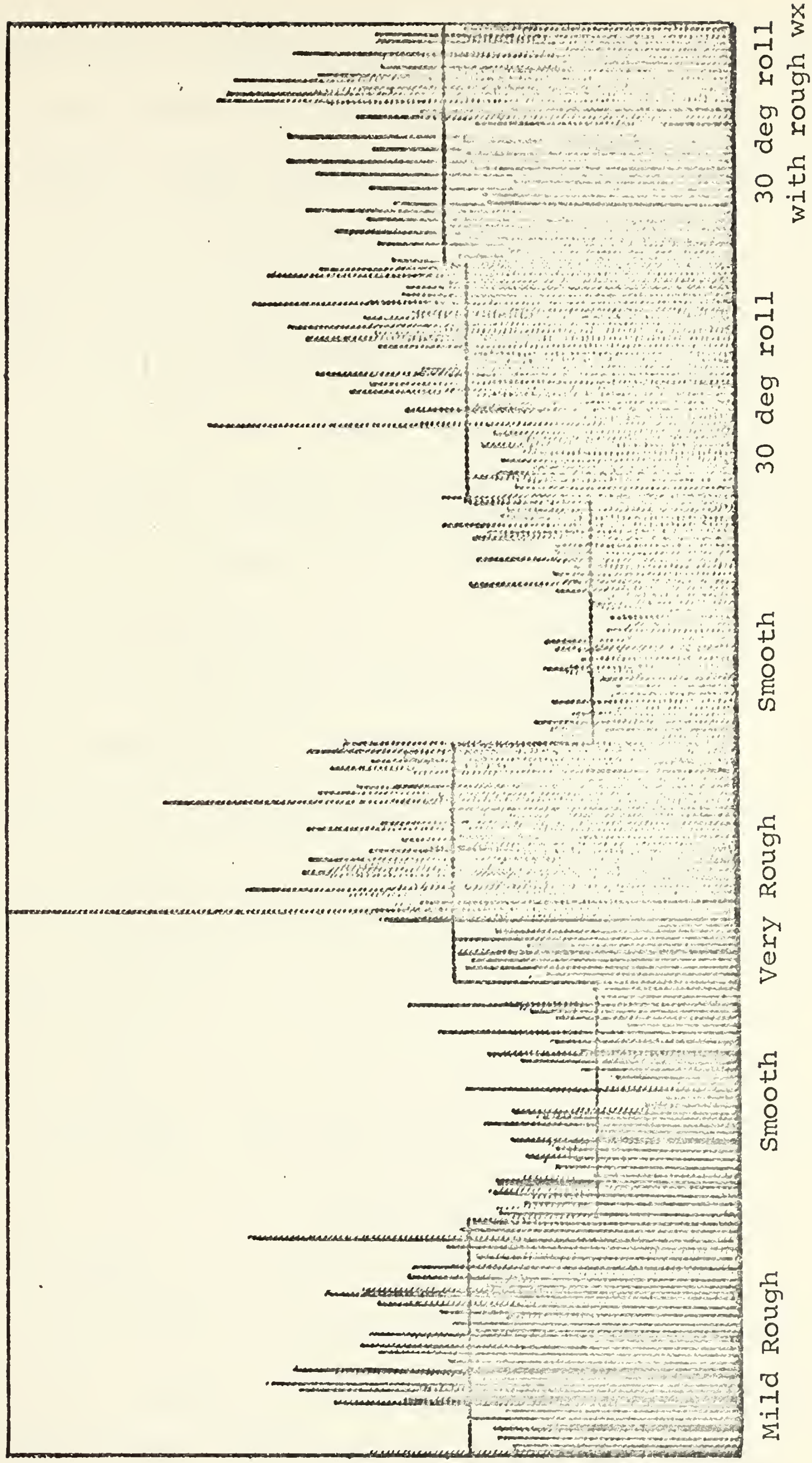

Mild Rough
Smooth
Very Rough
Smooth
30 deg roll
30 deg roll
with rough wx

Figure 5-4

It commenced with a segment where rough weather at a slow clock rate was presented to the subject. This was followed by smooth weather where the attitude variations are extremely slight and then another session where the subject again was in rough weather but at an increased clock rate. Following another smooth weather run the subject was asked to do 30 degree rolls, left and right, with no external attitude changes introduced. Finally, rough weather was introduced while the subject attempted to maintain his 30 degree rolls. The increased correlation while the subject is doing what is considered to be a more complicated task is obvious.

The superimposed line indicates the average value for each activity. Note that the rough weather at the higher rate of disturbance has a slightly greater correlation than that at the reduced rate. Likewise, the rolls with the rough weather show increased correlation. This indicates the general trend for most of the HUD runs. There were, however, significant variations from this norm. Occasionally, rough weather would show reduced correlation from that seen in smooth weather. This may be seen in Figure 5-5.

A given subject would maintain the same correlation tendencies for a given sitting but on subsequent days the trends might change. It is felt that this may indicate that regions within a general area, such as the motor cortex, may


Rough
Smooth
Smooth with rolls
Rough with rolls
Simulated rolls, no HUD
Relax

Figure 5-5

respond differently than their neighbors. Methods are now being devised to assure a more exact electrode positioning as slight variations in the way the helmet is placed on the subject's head may cause the electrode position on the skull to be slightly different than for a prior run.

Nonetheless, the general statement may be made that TWODET results show that, in the motor cortex, rough weather flying results in greater correlation than smooth weather, and smooth weather, in turn, more correlation than relaxed periods in the 70 to 100 Hz range.

DSKDET results indicate that perhaps it might be more accurately be stated that the signal content in frequency ranges from 60 to 140 Hz generally increases as the degree of flying difficulty is raised. Figure 5-6 shows a DSKDET result in the 80-100 Hz range; the upper trace being the signal content and the lower the correlation.

DSKDET allows an interesting excursion through the frequency spectrum for a given run. This is exemplified by Figure 5-7 which shows three different activities; relaxed, smooth and rough weather. The scaling is constant throughout the entire spectrum as the signal magnitude decreases sharply as frequency increases. Frequencies up to 180 Hz are shown without the signal content block as it almost exactly reproduces the correlation block.

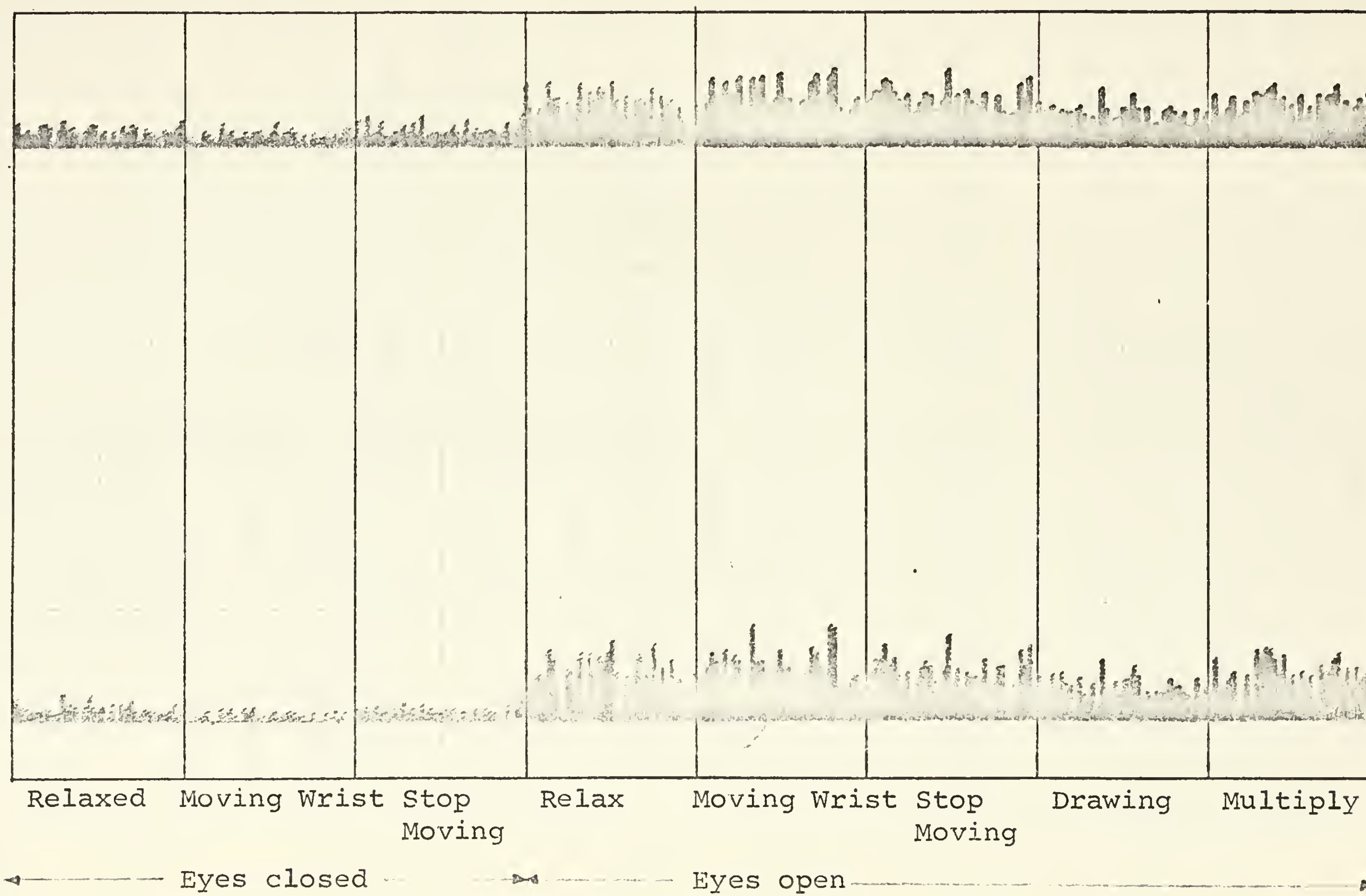


Figure 5-6. DSKDET. 80-100 Hz.
Note how upper trace (signal content)
is similar to lower trace (correlation)

Figure 5-7A reinforces HISCAN evidence that frequencies in the 4-8 Hz range increase when the subject is presented with a problem. Figure 5-7B illustrates once again that the greater the degree of relaxation, the greater the presence of alpha. The 20-40 Hz range has no significant difference between activities as is seen in Figure 5-7C. In Figure 5-7D, the 40-60 Hz begins to show increased correlation when flying the HUD and this increase is much greater by 70-90 Hz, Figure 5-7E. It should be kept in mind that the signal content data follows these trends closely. Jumping to 180-200 Hz, Figure 5-7F, it is evident that the signal content block is similar to prior correlation graphs but the electrode signals are becoming less correlated. At 400-420 Hz, Figure 5-7G, only rough weather remains reasonably well correlated.

The great spectral spread of the rough weather correlation may hint at myograms in this case, since in the average run correlation differences cease by 200 Hz. Large correlation can exist, however, at higher frequencies when, presumably, the possibility of myograms is eliminated. This is seen in Figure 5-8 which shows a comparison between a relaxed state and a subsequent smooth weather run, for the same subject as in Figure 5-7. This run was made on a different day with the same electrode position on the helmet. The graph shown illustrates the 600-620 Hz results. It is

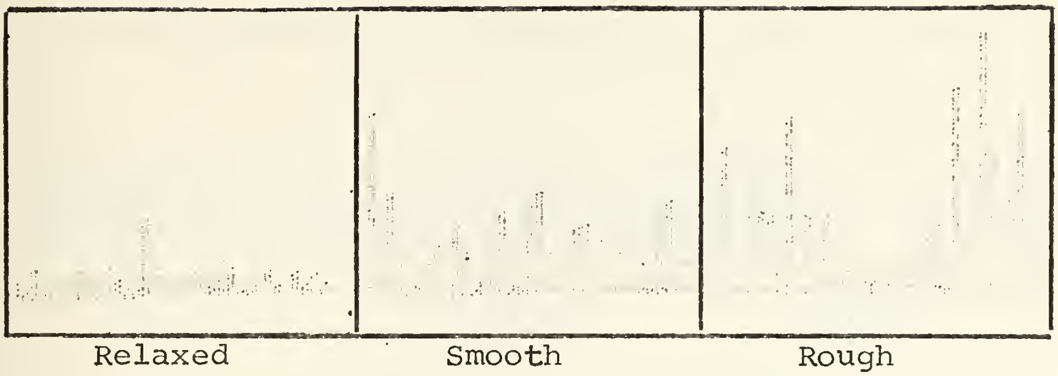


Figure 5-7 A. 4-8 Hz.

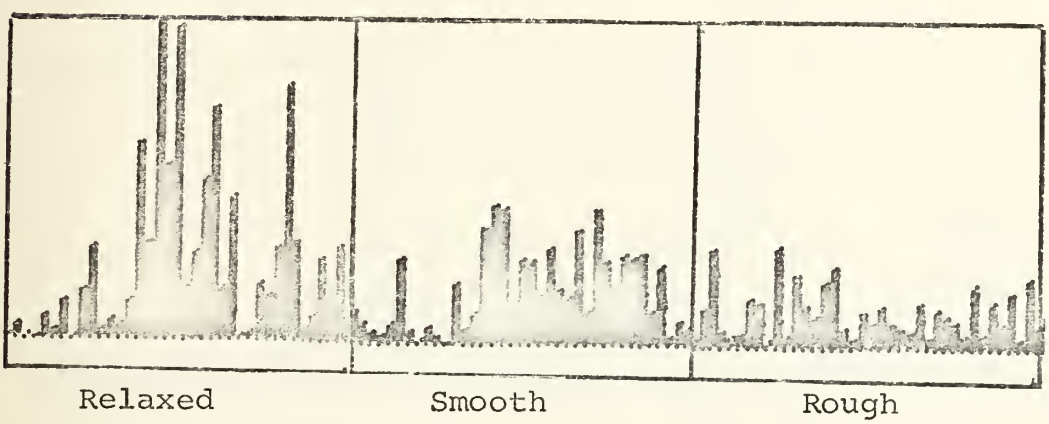
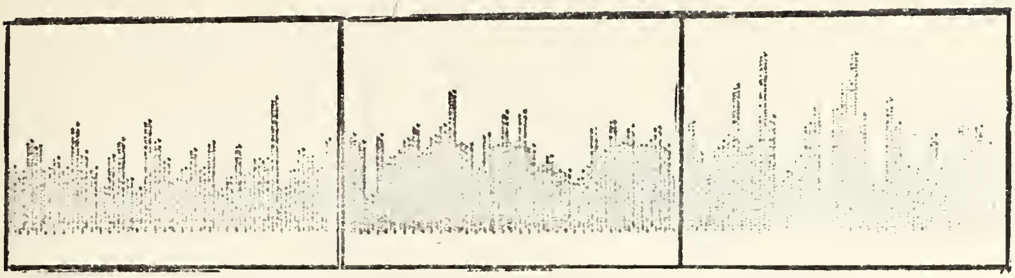
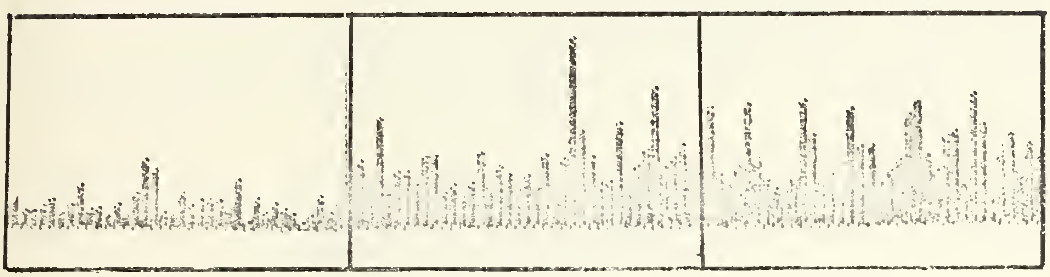


Figure 5-7B. 8-13 Hz.



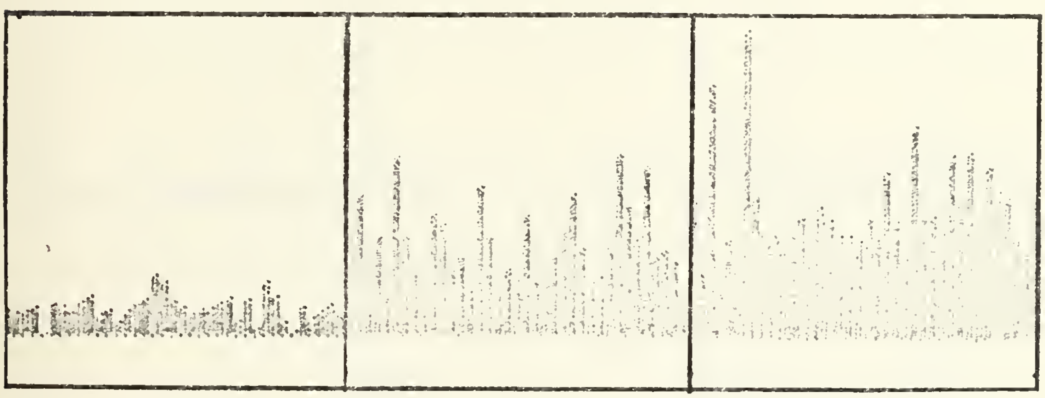
Relaxed Smooth Rough

Figure 5-7 C. 20-40 Hz



Relaxed Smooth Rough

Figure 5-7 D. 40-60 Hz



Relaxed Smooth Rough

Figure 5-7 E. 70-90 Hz

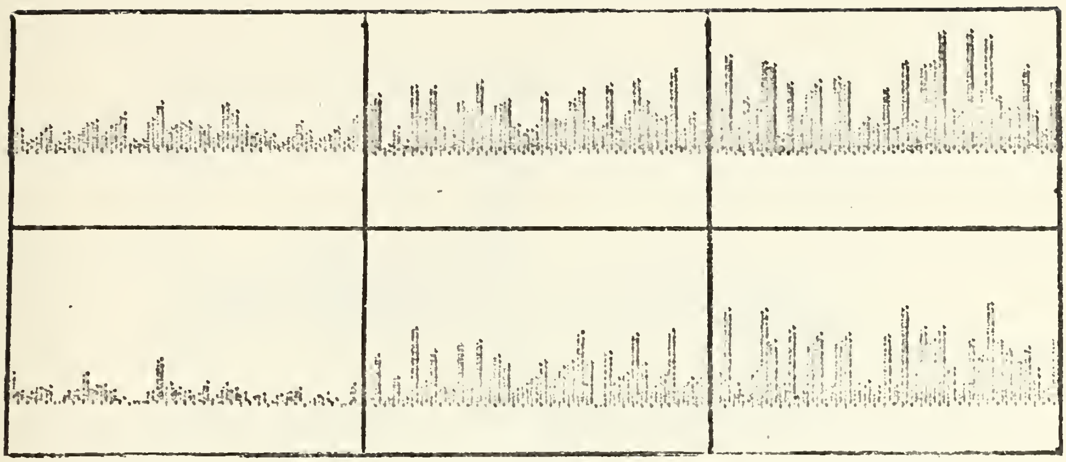


Figure 5-7 F. 180-200 Hz.
Upper trace is signal content,
lower is correlation

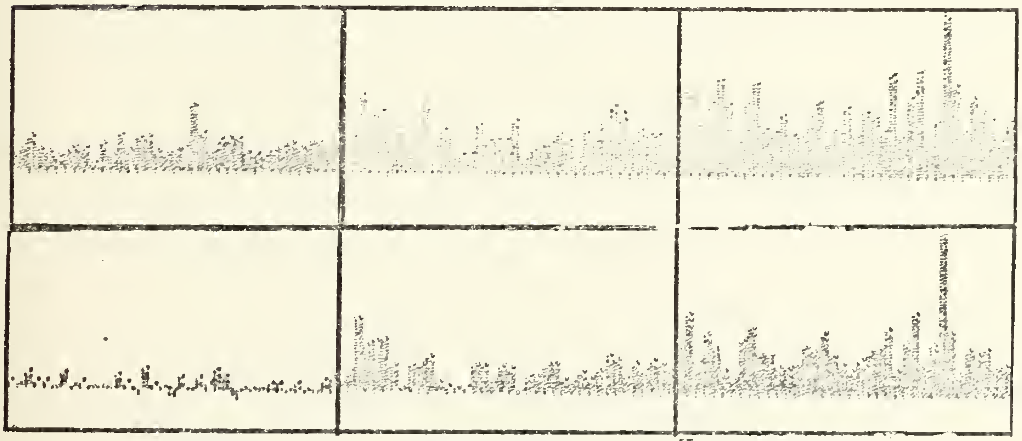


Figure 5-7 G. 400-420 Hz.
Upper trace is signal content,
lower is correlation

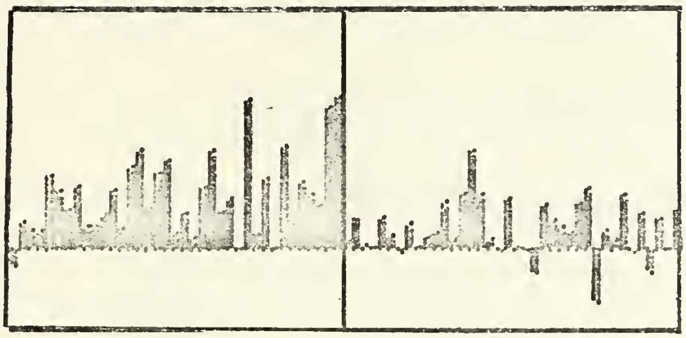


Figure 5-8. An example of large correlation at a high frequency in a situation where myograms are unlikely.

assumed that the subject was less likely to produce myograms when relaxed than when flying the HUD.

4. HUD Related Activities

a. Feedback

A major goal of the overall project is to establish a method whereby a subject can monitor his effectiveness at a particular task through some feedback system. If a region of the brain has preferred frequencies indicative of attentiveness or successful accomplishment of a task, it is desired that this information be fed back to the subject.

A method has been devised which adjusts the degree of brightness of a lamp located behind a translucent screen to the rear of the HUD display. The result is a halo-like effect around the HUD. Every 0.25 second TWODET sends a value indicating the extent of correlation to a peripheral of the computer where it is translated to a voltage to drive the lamp. The data base is still very limited and preliminary results will not be discussed.

b. Lighting Effects

Preparatory work was done to determine what affect the light from the feedback lamp might have on subjects in the frequency ranges to be observed. This investigation has only been conducted on two subjects to date, both of whom showed correlation differences (as large as 260%),

when lighting conditions were changed. Runs were always made with the subjects as relaxed as possible. Unhappily, the differences observed in the two subjects were in opposite directions. One subject evinced a marked degree of correlation in frequencies between 60 and 120 Hz when the lighting was increased, whereas the second subject showed decreasing correlation as the light intensity was increased. These limited results indicate that lighting effects must be further investigated before drawing conclusions from feedback experiments.

The above experiments were done with DSKDET and it must be recalled that this program is more sensitive to signals at the vertex than is TWODET. As the vertex is known to have marked visual evoked responses, further investigation should be done with TWODET or by using a different electrode recording mode with DSKDET.

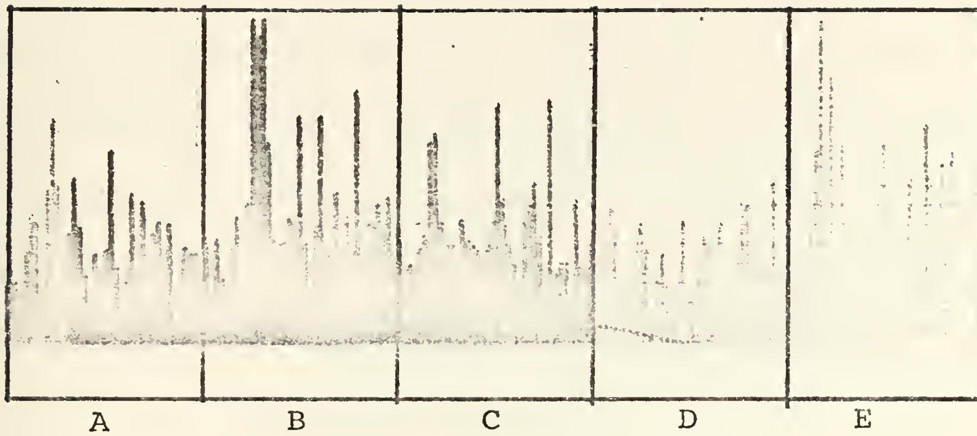
c. Random Motion

Much of the initial recent work has been done in the motor cortex and pre-motor cortex where, presumably, signals would exist which reflect movement. As flying the HUD involves finger, wrist and arm movement, it was desired to test the correlation of signals developed in these regions when a subject simulated the type of motion involved in HUD work.

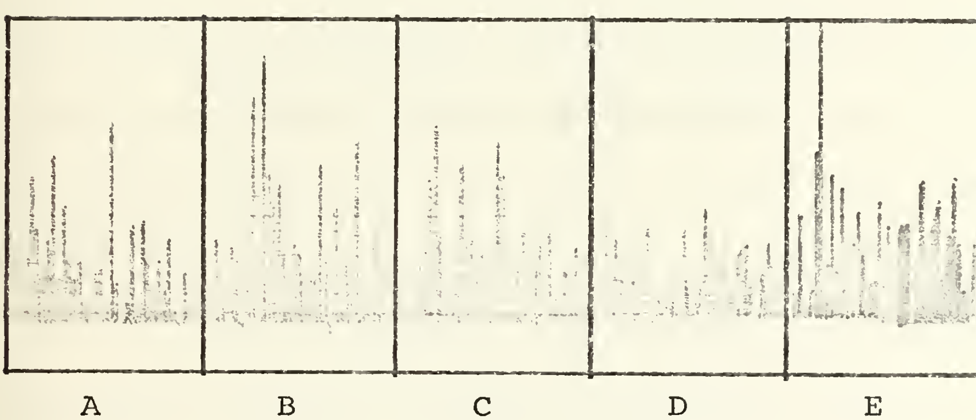
Subjects were directed to randomly move their fingers, wrist or arm for specified periods of time and then relax. Signals were analyzed with DSKDET in frequency ranges from 4 to 800 Hz. At no time did there appear to be any increase in correlation from relaxed to movement that was comparable to that seen when actually flying the HUD. It should be emphasized that the degree of motion of the subjects in these test runs was much more severe than that required to successfully fly the HUD.

In the 60-120 Hz range where the most marked degree of change are consistently noted, simulating flying motions resulted in an average increase of 10% in the correlation data over that when relaxed. Some subjects actually showed a slight decrease under these conditions. It is felt that if the data base is increased, the average correlation change may approach zero in this frequency range.

A surprising result was noted in the 20-30 Hz range (motor cortex). Subjects were asked to relax, then move their wrist or fingers randomly, then relax again on a command. In each subject observed, no change was noted during movement. However, shortly after movement ceased, the signal in this range dramatically increased in amplitude and slightly in duration with more frequent bursts, resulting in a spike in the signal strength and correlation graphs. Figure 5-9 illustrates this phenomenon.



A. Eyes closed while moving wrist
B. Eyes closed stop moving
C. Eyes open relaxed
D. Eyes open moving wrist
E. Eyes open stop moving



A. Eyes closed while moving wrist
B. Eyes closed stop moving
C. Eyes open relaxed
D. Eyes open moving wrist
E. Eyes open stop moving

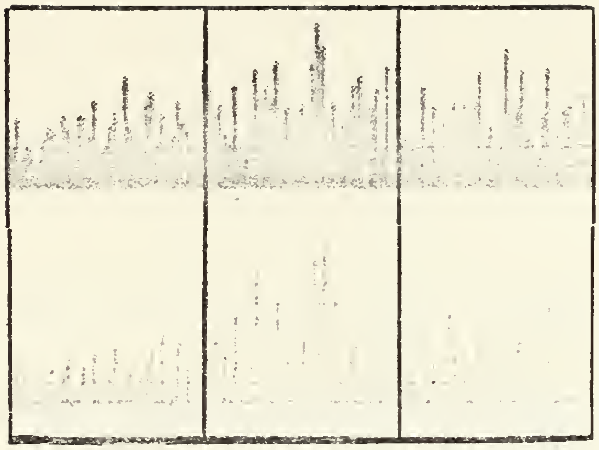
Figure 5-9. Illustrating the greatly increased signal following the cessation of motion.

When this sequence was performed with eyes closed, the latency of the increase was 2.5 seconds after ceasing motion, whereas with eyes open, the latency was 1.8 seconds. This response occurred on no other frequency range and may indicate a preferred frequency which shuts down some activated motor area. This same response appears for each of the three types of motion mentioned.

d. Purposeful Movement

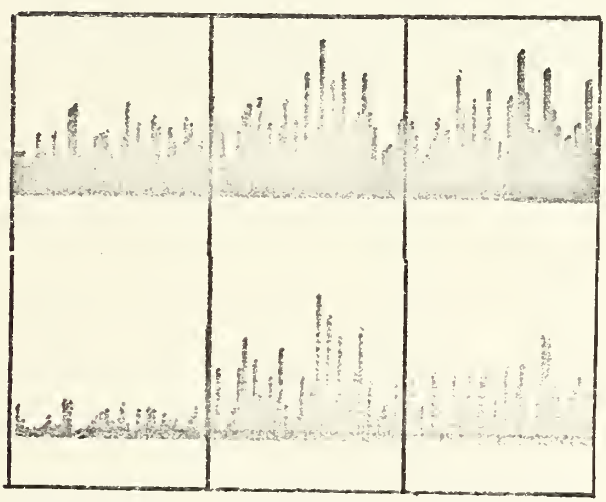
As the motor cortex is responsible for controlling purposeful movement, it is possible that random motion like that performed in the previously discussed experiments may be handled by lower brain centers. To test this hypothesis, subjects were asked to draw a picture of the HUD set-up, which was in front of them, and, secondly, to solve a tedious multiplication problem on paper. Results were impressive in two-thirds of the subjects. Figure 5-10 shows three test conditions for varying frequency ranges in the motor cortex.

At 40-60 Hz, the drawing and multiplication results begin to gain in signal strength and correlation, as is seen in Figure 5-10A. In the 70-90 Hz region, Figure 5-10B, the relative signal strength values remain the same, but drawing and multiplication results are significantly more correlated than during the relaxed period. Figure 5-10C shows that at 160-180 Hz there is no major difference in the



Relaxed Drawing Multiply

Figure 5-10 A. 40-60 Hz.



Relaxed Drawing Multiply

Figure 5-10 B. 70-90 Hz.

Figure 5-10 C. 160-180 Hz.

signal content between activities but the relaxed period has become even less correlated.

Other subjects showed much the same results although the relative strengths of the signal and correlation between drawing and multiplication might be reversed. An interesting anomaly is shown in Figure 5-11 where the first trace indicates the signal strength in one electrode, the second trace the other electrode, and the last the correlation data. This is for the 4-8 Hz range, an area found to be associated with problems. Again, the activities are; relaxed, drawing and multiplication. Note the great increase in signal strength in the one electrode during multiplication while the second electrode, located only 7/8 inch away shows none. This is perhaps illustrative of the need for more precise electrode positioning in future runs.

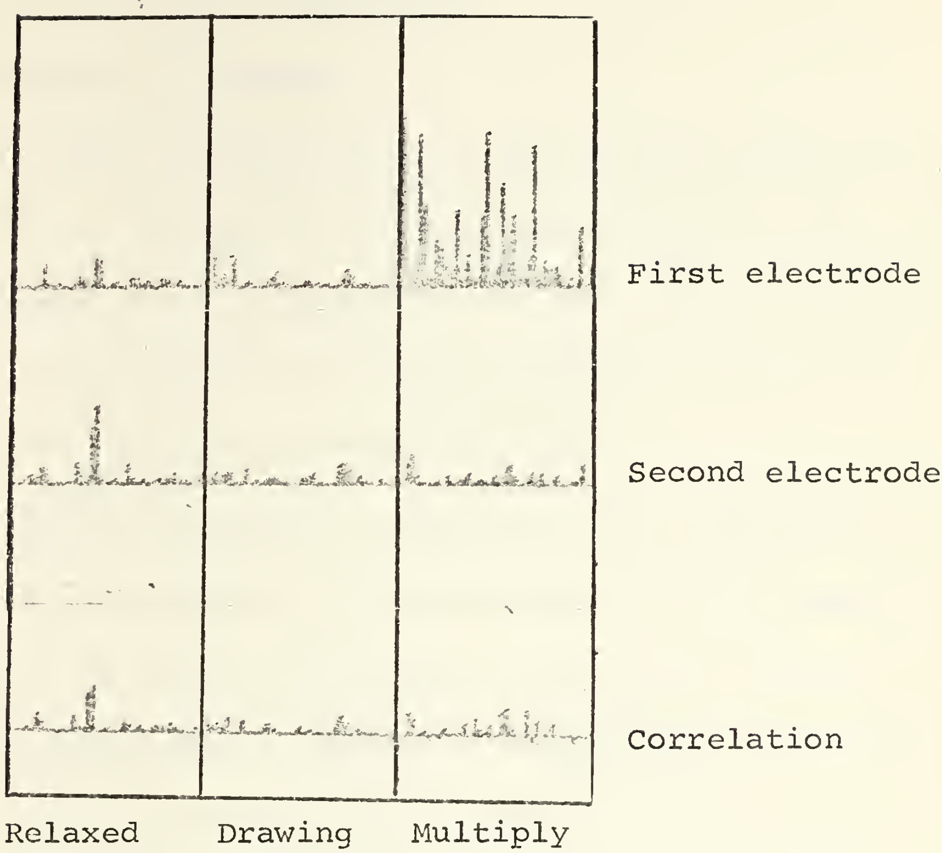


Figure 5-11. Illustrating the great difference that can occur in the signal between two closely spaced electrodes. 4-8 Hz.

VI. DISCUSSION

A. SIGNIFICANCE OF RESULTS

A great many of the results of the various experiments conducted by the team are extremely intriguing and lend themselves to speculation. The surface of the problem has just been scratched and solid conclusions based on the data obtained thus far should be drawn with care.

The preferred frequency concept as first visualized by Dr. George Marmont seems to have received continual supportive evidence throughout the project's history. Certain restricted comments may be made with confidence, and tentative theorizing on possibilities presented by the data is useful as a guide to future research in this area.

It is a new idea that there may be significance to the frequency activity above 30 Hz. For that matter, few investigators have suggested that frequencies above alpha range have any meaning at all other than to collectively indicate tension. The suggestion that discrete frequencies or small frequency ranges beyond alpha may be indicative of particular mental states or specific activities is novel.

It is felt that the body of information collected throughout the period of the research team's existence strongly supports this concept. Alpha range frequencies are seen to be

the largest magnitude, most noticeable frequencies in the relaxed individual, as reported by countless investigators. Evidence hints at there being independent alpha generation in frontal regions, rather than a shifting of phase as is often supposed. Associated with alpha, but clearly independent is the "20 Hz" signal. Its magnitude and duration seem, like alpha, to be directly related to relaxation. This signal has been observed to increase at the same time that alpha is decreasing and several subjects appeared to be able to voluntarily control the strength of the signal for limited periods of time. When using DSKDET, it was seen that in the 20 to 30 Hz range subjects showed a brief, but strong increase in signal intensity shortly after easing a particular movement.

The 4 to 8 Hz range, commonly referred to as theta, gave strong evidence of being associated with problem solving. The only attribute of this frequency range mentioned in the papers of other researchers is an association with shallow sleep. Every subject tested, with a variety of programs, showed an increase in this range when presented with a problem such as flying the HUD or simple multiplication.

None of the areas of the brain examined so far evinced any change in signal in the 30 to 50 Hz range for any of the activities devised to date. Beginning around 60 Hz in most subjects, and continuing as far as 200 Hz in some, there is

a definite increase in signal magnitude when solving problems or accomplishing a task which requires a certain degree of skill and attentiveness. This increase has been visible in the TOP and motor cortex. This same frequency range and, in some individuals, higher frequencies often show a marked increase in the correlation of the signal between two closely spaced electrodes. This may be attributed to the parallel processing nature of the cerebral cortex, i.e., the spread of activity to an entire functional column grouping of neurons in the cortex when there is sufficient stimulation.

B. PROJECT FUTURE

There are, in the data collected, enough exceptions to the general proposals above to indicate that in positioning electrodes it is necessary to be more specific than saying that events occur in general regions such as "the motor cortex". The occasional complete lack of correlation between two closely spaced electrodes may call for an electrode positioning system even more precise than the well known positional schemes in use by most investigators. It appears that continued research in this area could lead to the creation of a frequency mapping of the brain which would be a function of brain state or the type of activity the subject was engaged in.

When frequencies relating to attentiveness are more precisely identified and localized, the feedback experimentation can begin in earnest. The modifications discussed before as regards the simultaneous recording of analog signals with the EEG data will be of considerable assistance in determining the functional role of the many discrete frequencies observed with HISCAN.

A solid base has been established by team efforts over the past years, and these labors are just now beginning to bear fruit. The general trend of the project remains to investigate the frequency spectra of the EEG and to establish functional relationships between frequency and mental or physical state. These relationships will then be used to feed back to a subject information as to his performance and degree of attentiveness to a particular task. Hopefully, these methods may also lead to an ability to create in an individual an atmosphere conducive to learning or to increase his ability to assimilate and act wisely on new information or situations.

LIST OF REFERENCES

1. Thompson, R.F., Patterson, M.M., Bioelectric Recording Techniques, Part A, Academic Press, 1973

2. Eccles, J.C., The Understanding of the Brain, McGraw Hill, 1973

3. Creutzfeldt, O.D., Watanabe, S., Lux, H.D., "Relations Between EEG Phenomenon and Potentials of Single Cortical Cells", Electroencephalography and Clinical Neurophysiology, Vol. 20, p. 19-37, 1966

4. Rosenthal, F., "Relationships Between Positive-Negative Extra-cellular Potentials in Pyramidal Tract Neurons", Electroencephalography and Clinical Neurophysiology, Vol. 30, p. 38-44, 1971

5. Williams, P.L., Warwick, R., Neuroanatomy of Man, W.B. Saunders, 1975

6. Dollar, S.E., "Multidimensional Analysis of the Electroencephalogram Using Digital Signal Processing Techniques", Naval Postgraduate School, 1973

7. Wicklander, E.R., "An Analysis of Electroencephalograms", Naval Postgraduate School, 1975

8. Stockslager, W.E., "Computer Modeling of the Electroencephalogram", Naval Postgraduate School, 1974

9. Marvel, D.C., "A Versatile System For Interfacing Subject To Task In EEG Analysis With Biofeedback", Naval Postgraduate School, 1975

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